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ANNOTATED BIBLIOGRAPHY ON BITTER-PIT

With an introduction by

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THE PREVENTION OF BITTER-PIT

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In spite of the numerous investigations of the disease which have been carried out in different parts of the world, bitter-pit remains a major source of wastage in certain varieties of apple, and critical information as to the causal factors is still lacking. Many theories of the origin of bitter-pit have been advanced, but so far none of these can be accepted as proven. Indeed, it is not even known whether the injury to the cells, which eventually results in their death and browning, actually occurs while the apple is still on the tree or whether it may also occur after the fruit is picked.

But although there is no certainty as to the causes of bitter-pit, certain characteristics of the disease are now definitely established, and with knowledge of these the extent of the losses may in some instances be diminished very considerably. Thus for certain varieties of Australian, New Zealand and American apple, there is good evidence that the liability to develop bitter-pit in storage diminishes with increasing maturity at the time of picking, and for the Cleopatra apple of Western Australia, picking at a certain stage of maturity, as defined by the ground-colour and iodine tests, appears to be a practicable method of decreasing the losses from bitter-pit. With other varieties, however, such as the Cox's Orange Pippin of Tasmania and New Zealand, later picking may bring with it a danger of increased low temperature breakdown in types of Cox's susceptible to this trouble, and the usefulness of late picking will thus probably be restricted to fruit which is not susceptible to the breakdown. In general it is probably safe to say that the value of late picking in diminishing losses from bitter-pit has not yet been sufficiently tested commercially, probably in large measure because of the difficulty of providing the grower with a simple method of judging maturity. A reliable index of maturity is in fact an urgent requirement both for research and commercial use, and the development of new tests of maturity and further trials of the present ones, including that of respiration, are essential features of research programmes.

Of other characteristics of bitter-pit we may note that susceptibility to the disease increases with increasing size of apple, and that fruit from light crops, from young trees and from trees given late irrigation, is particularly liable to pit. Where the latter conditions occur then it may be advisable to prohibit the export of apples above a certain size. Moreover, since light crops, young trees and irrigation are all associated with vigorous growth, it seems desirable, in further investigations of bitter-pit, that records should be taken of the vigour of the trees.

Unfortunately in the preceding paragraphs we have almost exhausted the known characteristics of bitter-pit and we must admit that as regards the effects of a whole series of factors such as rootstock and scion, soil conditions and manuring, rainfall and climate, pruning and thinning, practically nothing critical is known. For the investigator seeking to prevent bitter-pit there is then the choice of experimental work along many lines, and we may usefully consider which lines appear to give most promise of success.

As judged by the possibility of quick results there seems to the writer little doubt that investigations of the effects of the following factors, viz. maturity at picking, position of fruit on tree, size of crop, type of pruning, and effect of blossom or fruit thinning, are particularly likely to bring success. Moreover any results obtained in these investigations should be readily

applicable commercially, since, unlike climatic and soil conditions, the above factors are all such as can be readily controlled by the grower.

In order to ascertain the influence of rootstock, soil conditions, rainfall, etc., comprehensive orchard and storage investigations are required. These investigations should be planned to extend over a period of years and should include careful recording of the temperature, rainfall and drying-power of the air in the orchards throughout the growing season. Another approach to the problem of determining the effect of climatic conditions is to control artificially certain climatic factors, and experiments of this type have already produced results of considerable promise. We refer to the work of Wallace at Long Ashton, where apple trees are being grown under controlled conditions of temperature and of soil and air-moisture. This work may show whether either the temperature or water-relations factors can be regarded as determining the development of bitter-pit. Other experiments in which the water-relations are being artificially controlled are those of Tindale in Victoria.

Hitherto little attention appears to have been given to the question of the variation in susceptibility of different trees to bitter-pit. So far as we are aware, it is not known to what extent apparently similar trees, growing adjacent to one another, may differ in susceptibility ; nor whether trees, which are highly susceptible in one season are also highly susceptible in another. Knowledge of this kind is clearly an essential preliminary in certain investigational work, and might be of considerable commercial value. Thus if certain trees in an orchard were known to produce a high proportion of bitter-pit each season, the fruit from these trees might be rejected as unfit for export, and the pit-free fruit from the less-susceptible trees would then not suffer in price from admixture with pit-liable apples.

Finally we come to the effect of storage conditions on the development of bitter-pit, and here again there are many deficiencies in our knowledge. While in general immediate storage at low temperatures seems to retard the development of bitter-pit as compared with storage at higher temperatures, there is evidence that pre-cooling, i.e. rapid cooling to the temperature of storage, results in considerably more bitter-pit than delayed cold storage. In view of the advice generally given for the avoidance of bitter-pit, namely later picking coupled with pre-cooling, further work on the effect of immediate and delayed cold storage is desirable.

So far as we know there is no evidence of the influence on the development of bitter-pit in storage of either the humidity or the carbon dioxide and oxygen contents of the atmosphere, and experiments on these factors are needed. Even if gas-storage conditions have no direct effect on the development of bitter-pit, the retarding effect of gas-storage on ripening and on the development of breakdown should allow the fruit to be picked at later maturity with consequent diminution of bitter-pit. The possibility that treatment with ethylene after picking may in some instances decrease the amount of bitter-pit requires further exploration.

NOTES ON BITTER-PIT BIBLIOGRAPHY*

Differentiation between bitter-pit and other corky diseases†

COBB (1892, 1895, 1897, 1903), who first suggested the name of bitter-pit, described two diseases, his original "obscure disease" and that later known as bitter-pit. While recognizing differences between them he noted at the same time similarities which led him to assign a common cause, i.e. insect puncture or "stigmonose". Carne (1927[2]), who gives a very clear statement of Cobb's position (from which the above is taken), points out that McAlpine (1912, 1st Rept., p. 17) regarded the two troubles as being merely forms of the same disease, which Cobb never at any time stated.

MIX (1916) describes separately bitter-pit or fruit-pit, cork and drought spot, but considers all three to be closely related. Of cork and drought spot he says: "It is evident that we have under consideration not two distinct apple diseases, but at the most two types of the same disease." Suggesting a cause—excessive transpiration of fruit or failure of the vascular network over large areas—he says: "It is not intended to advance this theory to explain the cause of true fruit-pit or stippen, which occurs in a late stage of the fruit's growth and is said to develop in storage".

BROOKS AND FISHER (1918) differentiate between bitter-pit caused by excessive moisture, and drought spot and cork, which are due to drought.

BROOKS AND OTHERS (1926) describe and illustrate apple spot disease and point out the differences between Jonathan spot, bitter-pit, and drought spot. "Bitter-pit differs from Jonathan spot thus: it is confined almost entirely to the blossom half of the apple, the spots are bruise-like, more sunken, contain more dead brown tissue and are more deeply seated. Jonathan spots . . . are usually entirely removed in peeling an apple, but the bitter-pit spots are cut in and made more evident."

RIGG AND TILLER (1927) show the dissimilarity of bitter-pit to certain other diseases of New Zealand apples.

CARNE (1929) endeavours to reduce to order the existing confusion of nomenclature and conception. He distinguishes and describes four types of corky disease of orchard origin. Three have been previously described by Mix or McAlpine. The fourth, blotchy cork, is an orchard disease confused with true bitter-pit in Australia. To these four he assigns fresh names, each of which has the termination "cork". True bitter-pit is distinct from these and "for the most part" originates in storage. For this the name storage-pit is proposed. For the true bitter-pit which originates in the orchard the name tree-pit is suggested.

IN THE FIELD

Physiological origins

JAEGER (1869). Pitting is due to rapid transpiration in liable varieties.

CRAWFORD (1886). Pitting is due to the trees being young and making too much sap when planted in a damp situation (quoting a grower's opinion).

WORTMANN (1892). Concentration of the sap, following the loss of water by transpiration, occurs in the pulp cells adjoining the vessels, and the acidity of the concentrated sap is the direct cause of the injury.

ZSCHOKKE (1897) agrees with Wortmann that the disease is connected with transpiration and considers that the unequal conduction of water in the fruit flesh is one of the most important factors.

* The references to unpublished memoranda or notes thereon by Barker, Kidd, Knight and Wallace, all for 1934, are to memoranda or notes made by these workers as a result of a conference on bitter-pit held at New Zealand House, London, on June 6th, 1934.

† In these notes no attempt has been made to disentangle tree pit and other corky diseases from storage pit unless the authors themselves have done so.

LAFAR (1898). Pitting under the skin is due to cell rupture followed by oxidation of its tannin.

JONES AND ORTON (1899). Spots are associated in distribution with that of the vascular bundles occurring at or near the ends of the veins which ramify in the flesh of the fruit. A summary of the factors to which bitter-pit has been attributed is given.

KIRCHNER AND BOLTSHAUSER (1899). The disease is probably caused by the gradual loss of water from transpiration of the fruit.

SEUFFERHELD (1900). Liable varieties are those with large fruits which are protected against excessive transpiration by a smooth skin. Rough skinned, freely transpiring sorts are not liable, even when fruits are large.

SORAUER (1900). Cells rupture during process of swelling, and this taken in conjunction with the presence of starch, which is absent from the surrounding healthy tissue, shows that the disease began before maturity was reached.

CLINTON (1903). A physiological trouble resulting from too great loss of water at these points where the spots occur and (1910) a physiological disease of which the cause is unknown.

MASSEE (1906). Purely physiological and considered to be due to too high an atmospheric temperature during early period of ripening.

FARMER (1907). Failed to establish parasitic origin for pit in apples from the Cape. Remarks that cells of the affected area are always full of starch in marked contrast to surrounding healthy cells.

DAVIS (1907) states that with apples from the Cape it is of a purely physiological nature and found only on grafted trees. Naturally produced varieties (seedlings) are all immune. This last statement is not upheld by McAlpine (1913, 2nd Rept.) for Australian apples. Seedlings there are equally liable with grafted plants.

BROOKS (1908). Due to abnormal physiological conditions.

SORAUER (1909). Failure of certain cells to accumulate the proper amount of organic material for complete maturity of the fruit. As a consequence they perish prematurely. This is caused perhaps by dryness of the soil in the early stages of growth.

EVANS (1909), South Africa. Excessive transpiration during day followed by complete cessation during night with vigorous root action continuing unchecked. The bursting of the cells due to too great internal pressure results in formation of dry and tough bitter-pit spots. (See Smith, 1926, below.)

DIAKONOFF (1910). A consequence of too rapid growth of individual groups of the cells of the flesh. It occurs wherever the conditions are very favourable to hastening the ripening process either on the tree or in store.

GÜSSOW (1911). Causal factors are rapid loss of water from the fruit and inability to make this loss good with sufficient rapidity.

SCIENTIST (1911). Possibly an accumulation of tannin or malic acid causing death of cells.

GRIFFITHS (1911). A constitutional weakness in the fruit due to overgrowth. Remedies lie in proper drainage and restraint in manuring, irrigation, and pruning.

BOWLES AND OTHERS (1911). No bacteria or fungi have been found. Apparently a disease of physiological origin.

WHETZEL (1912). A season of normal or uniform growth without sudden checks or stimulation, whether due to climate or cultivation, produces the least amount of pit.

MCALPINE (1916) in his final report (5th) concludes : " The result of this investigation goes to show that the primary cause of the trouble is the extra pressure of the sap in the outermost layer of pulp cells to begin with, causing them to burst and collapse, together with the rupture of the vascular network associated with them, . . . whatever tends to regulate the flow of sap and distribute it to the various fruit buds so that each receives its due share without being overgorged will also tend to prevent pit." (See Smith, 1926, below.)

Mix (1916). Insufficient moisture supply to the fruit accompanied by excessive transpiration possibly due to the leaves robbing the fruit of moisture. Mix produced corky areas in fruit on cut shoots by stimulating transpiration. Smith (1926) says there is little resemblance between "cork" and "bitter-pit". Carne (1927[2]) is of the opinion that Mix has shown that cork and bitter-pit are entirely distinct, though apparently related diseases. Atanasoff (1933) interprets Mix as saying that cork and bitter-pit are not two distinct diseases, but at most two types of the same disease.

Brooks and Fisher (1918). "There is a close relationship between soil water supply of the orchard and the development of bitter-pit in storage." (See Soil moisture.)

McAlpine (1921) restated the ruptured cell theory (see Smith, 1926, below) and adds that rapid fluctuation of temperature during the growing season is an exciting cause of bitter-pit. (See under Weather.)

Heinicke (1921) says both tree-pit and storage-pit are due to the same cause, starvation, although the former is apparently caused by drought conditions unfavourable to an adequate supply of nutrients and the latter is associated with an excessive supply of moisture or size producing nutrients. In the case of storage pit the drought conditions are set up when the apple is picked, especially if it is not mature and requires further nutrient to complete development. The physiological reasons supporting this argument are discussed.

Herbert (1922) supports the crushed cell theory. "Pitting takes place in the apple for the most part at a time when the starch is being converted into sugar. It is evident that when there is a sudden rush of sap into the apple the cells which have had their starch converted into sugar will swell to a greater extent and more rapidly than those cells which are still supplied with starch. The rapid distention of the cells is resisted on the outside of the skin. Their force of expansion results in the crushing of those cells whose starch transformation is backward. This accounts for the presence of quantities of starch in the dead pit cells."

Kidd and West (1923) put forward the suggestion that apples subjected to extremes of temperature while in growth, e.g. a hot day followed by a cold night, may develop an internal atmosphere during the day which, while harmless at higher temperatures, will cause local brown heart (bitter-pit) in badly aerated spots in the flesh when the lower temperature supervenes. (See Smith, 1926, below; and Weather.)

Kaiser (1923). Desiccation of vascular cells due to rapid evaporation of inadequate water supply. The cell sap and the acids which it contains become concentrated in the cells from which the water is withdrawn and eventually destroy the protoplasm, which turns brown as a result of subsequent oxidation with atmospheric oxygen.

Smith (1926) discusses the more reasonable of various theories hitherto advanced. Of the *theory of local desiccation* which was one of the most popular, he writes: "The occurrence of flaccid collapsed cells in the midst of healthy turgid tissues can only be explained, on the grounds of water loss, by supposing that the osmotic pressures initially developed in these cells are so small that a fatally large amount of water is withdrawn from them before their saugkraft (water absorbing power) balances that of the neighbouring cells. Such an eventuality may indeed be advanced with some degree of plausibility. The inhibition of starch metabolism, which is a normal feature of bitter-pit, might result in the failure of these cells to develop a sufficiently high osmotic pressure, owing to the absence of sugar. But this view assumes the impermeability of the pulp cells to sugar, which is uncertain." On the whole Smith finds the theory of localized drying out of the cells to have little to recommend it and to be open to grave theoretical objections. He considers that desiccation is more probably a result than a cause of the death of cells. He holds that *theories of cell rupture* (see Evans, 1909) are impossible for the reason that cells do not burst through excess water but pass it out through the walls into the intercellular spaces (producing water core), whence it may be reabsorbed without trace of

cell rupture. (O'Gara, P. J., Studies in the water core of the apple, *Phytopathology*, 3 : 12 : 1912). The *theory of asphyxiation* (see Kidd and West (1923) above) *due to fluctuation of temperature* is dismissed by Smith. "In Tasmania the climate is generally equable but bitter-pit is often severe." There the variety, age, and soil conditions appear to be of more importance than temperature fluctuations in the occurrence of bitter-pit. (See Weather.)

Brooks, Cooley and Fisher (1926). Bitter-pit due to over-stimulation of the fruit during the growing season. "Heavy irrigation and heavy rainfall during the last few weeks before picking are particularly favourable to the disease." (See Soil moisture.)

Brooks and Fisher (1926). Bitter-pit is largely due to over-stimulation during the latter part of the growing season. Drought spot is caused by quite other conditions.

Heald (1926) reviewing the evidence considers that bitter-pit is due to disturbed water relations but that there is no unanimity as to the exact way in which the disturbance operates.

Carne (1927[2]). "Bitter-pit is a necrosis of immature starch-filled tissues of rapidly growing apples, resulting from excessive transpiration followed by osmotic action between the starch-filled cells and those in which starch has been largely or completely changed to sugar."

Valleau and Johnson (1928) present evidence suggesting that drought spot, cork and bitter-pit are diseases of the same general nature as frenching of tobacco, all being due to nitrogen starvation of the affected tissues.

Thomas and Raphael (1932) describe an attack of cork in a Tasmanian orchard which was associated with swollen and malformed wood growths at the tips of the branches and spurs which had borne the fruit. Atanasoff (1934) cites this phenomenon as an indication of the virus nature of bitter-pit.

Barker (1934) discusses briefly the experiments at Long Ashton (see in various sections under Wallace (1934)), and considers that they point to fruit being predisposed to bitter-pit while still on the trees, possibly through environmental factors.

Virus

Atanasoff (1933-4) propounds the theory that bitter-pit, in which he includes as types of the same disease drought spot, cork, tree-pit of Carne, and storage-pit, is a virus disease. His suggestion (in 1933) is entirely based on his reading between the lines of existing literature, mainly McAlpine and Mix. His main argument is based on his interpretation of some of McAlpine's grafting experiments, the significance of which he says McAlpine missed. Mix (1916) is quoted at some length to show that his observations unwittingly "speak of the virus nature of drought spot and cork". Atanasoff is of the opinion that there is a close and sometimes complete resemblance between bitter-pit, potato streak, potato rot necrosis, tomato streak, plum pox, grape measles and buckskin of cherry, which he states are all virus diseases.

[Is not the acknowledged fact that a tree may suffer from corky diseases one year and be free the next contrary to the theory of virus infection?—Ed.]

Atanasoff (1934-5) has now initiated grafting experiments which he claims have already proved the transmissibility of bitter-pit (apparently, all corky diseases) by virus infection. He claims that trees budded with infected buds, though they have not yet fruited, have developed on their leaves spots or blisters and the mottled leaf which "always accompanies bitter-pit" in Bulgaria.

[It is understood that Mr. W. M. Carne has a repetition of McAlpine's grafting experiments in progress.]

Insects or fungi

Reichelt (1884) attributes the disease to a fungus and the bitter taste to diacetyl grape sugar.

Cobb (1892, etc.) (see under Differentiation between bitter-pit and other diseases) suggested stigmonose or insect puncture as a common cause of the two diseases he described.

Greig-Smith (1911). The result of some enzyme or poison injected by sucking insects.

Weather

Fluctuations of temperature during growth an exciting cause of bitter-pit.

For—Schneider (1909)
Evans (1909).
Whetzel (1912).
McAlpine (1921).
Kidd and West (1923).

Against—Smith (1926).

Kaiser (1923). Damp, sunless weather causes bitter-pit.

McLarty (1925). Losses in British Columbia from bitter-pit in 1924 " were far above the average, probably owing largely to the dry spring and delay in applying the first irrigation. . . . The fruit reached maturity a fortnight earlier than usual ".

Baudys (1929) ascribes a severe outbreak of tree pit in Moravia to a very hard winter followed by an exceptionally dry spring resulting in retarded growth.

Wallace (1932) discusses various types of cork injury which have recently come under his notice in English fruit areas. A sudden period of high temperature sometimes accompanied by a soil moisture deficiency can usually be associated with the outbreaks.

Overholser and others (1933). High temperatures, periods of low relative humidity, strong drying winds during the growing season are among the factors producing cork and drought spot. (See also Wallace, 1934, under Soil moisture.)

Soils

McAlpine (1915, 4th Rept.) gives results of investigations which tend to show that least pit is produced on the lighter soils.

Tiller and Chittenden (1933) give figures to show a marked difference in susceptibility to the disease shown by Cox's Orange Pippin from two different types of soil, those grown on fertile light loam being much superior in storage quality to those grown on clay loam deficient in nutriment.

Overholser and others (1933). Too close planting reducing the mass of soil available to each tree and low soil temperatures which produce root injury are included among a number of factors causing cork and drought spot. (See Root injury.)

Barker (1934) alludes to differences in susceptibility of Cox's Orange Pippin from different orchards.

Soil moisture

Crawford (1886). " Induced by excessive growth caused by damp situation." S. Australia.

Despeissis (1903). In Western Australia the affected areas are the damp localities of the plains and not the well drained soils and gravelly slopes of the Darling Ranges.

Brooks and Fisher (1918) in U.S.A. show a close relationship between soil water supply of the orchard and the development of bitter-pit in storage, heavy irrigation greatly increasing the disease, light irrigation reducing it. Drought spot and cork on the other hand are drought effects.

Kaiser (1923), Germany, assigns excessive irrigation as one cause (possibly not from his own observations—Ed.).

McLarty (1925) blames a dry spring and delay in applying the first irrigation for the greater amount of bitter-pit in British Columbia in 1924.

Brooks and others (1926[1]). " Apparently due to derangements in soil moisture conditions."

Carne, Pittman and Elliott (1930) showed that sudden drought conditions following normal climatic conditions are a cause of cork.

Tindale (1932), Victoria, Australia. Continuous watering produced a high percentage of tree-pitting. A high correlation was found to exist between tree-pitting and store-pitting.

Overholser and others (1933). Growth on soils of inadequate moisture holding capacity and insufficient or excessive irrigation are among the factors which produce cork and drought spot, largely through root injury.

Wallace (1934). At Long Ashton bitter-pit has never occurred in fruit whose growth has been severely restricted by drought. In pot experiments with Bramley's Seedling with high soil moisture, high temperature and low atmospheric humidity good crops were obtained. The fruit showed large percentages of crinkle, blotchy cork and water core. The apparently sound fruits developed 100 per cent. bitter-pit in ordinary store.

Manures

Wortmann (1892). An excessive application of nitrogenous fertilizer might produce bitter-pit because the tissue of the apple would then contain too much nitrogen in comparison with the carbohydrates which are also needed for the formation of protoplasm and new tissue.

McAlpine (1915, 4th Rept., p. 59). Influence of manures on bitter pit varied with the locality. Green manuring in W. Australia gave lowest percentage, probably through regulation of soil moisture by formation of humus.

Heinicke (1921). Baldwins in sod, which were treated with sodium nitrate on one side only, developed more Baldwin spot on the *untreated* side.

Kaiser (1923). The disease is favoured by the abundant application of nitrogenous manures when the fruit is already well developed.

Wallace (1934). High potash fruits from vigorous trees have always shown more bitter-pit than fruits from trees definitely deficient in potash. (See also Wallace, 1934, under Soil moisture.)

Root injury

Overholser and others (1931). Winter injury to roots of Jonathan, Rome Beauty, Esopus, White Banana, is held responsible for the subsequent excessive development of cork or drought spot. In a subsequent paper (1933) the same authors include root injury caused by low temperature or too deep cultivation or over or under irrigation among the factors responsible for cork and drought spot.

Poisoning

Anon (1911[1]). Spray damage by arsenate of lead alleged.

Scott (1911). Chemical tests support the suspicion of arsenate injury, but are inconclusive.

White (1911) suggests slow local poisoning on the ground that toxic action upon the cell diastase was necessary to explain persistence of starch grains in bitter-pit spots.

Ewart (1911, 1913, 1914[1], 1914[2], 1917) supported White.

O'Gara (1911) showed clearly the difference between arsenic spotting and bitter-pit spots.

Breidahl and Rothera (1914-15) considered Ewart to be in error.

McAlpine (1915, Rept. 4, p. 23) showed that unsprayed trees developed bitter-pit before spraying became an orchard practice and says that, if there is poisoning, absorption through the roots must be postulated.

Crabill and Thomas (1916) were unable to substantiate the poison theory through the skin.

Smith (1926) concisely sums up the arguments for and against. He considers the theory of poisoning was originally discredited because of the easily refuted suggestion that it came from spraying materials. The theory of absorption of minute quantities of poison through the roots which was later substituted for that of absorption through the skin of the fruit (McAlpine, 1915, 4th Rept.) is a possibility without any strong evidence. He suggests further research on this.

Rootstock influence

McAlpine (1911-16 Repts. 1-5) could find no evidence of rootstock effect on bitter-pit.

Carne, W. M. (1927[2]) points out that in some but not all varieties the picking of the large terminal apples first under the impression that they are ripest is often the cause of subsequent pit development. In reality these apples are the least mature. (See Maturity at harvest.)

Atanasoff (1933) claims that McAlpine interpreted his results wrongly and that there is distinct evidence of the transmission of (the virus of) bitter-pit from stock to scion. (See Virus.)

Overholser and others (1933) consider there is some evidence that the recent development of cork spot of pears can be correlated with the coming into use of the Japanese *Pyrus serotina* as a rootstock.

Knight (1934) points out the possible influence of rootstock through the nutritional factor. A tree of restrained vegetative growth is less liable to pit than a vigorously vegetative one. Trees on a dwarfing stock which suddenly become vigorously vegetative should be suspected of scion rooting. In all orchard experiments records of tree vigour should be taken.

Wallace (1934). At Long Ashton only one suggestive result has been obtained out of many experiments. Cox's Orange Pippin on East Malling type II, under four manurial treatments, N.K., K., N., nil, showed bitter-pit in cold store with K. and N.K. On East Malling type IX it showed low temperature breakdown but no bitter-pit with any of the treatments.

Position on tree

Heinicke (1921), U.S.A., referring to tree-pit presents data which he claims show (1) that the lateral fruits of a cluster are more likely to develop bitter-pit than the central fruits ; (2) that spurs with the most disease are usually found at the base of the branch ; (3) that apples on weak wood are more susceptible than apples on wood of fair vegetative growth. (Heald, 1926, and later editions, gives a good summary of this paper.)

Kaiser (1923). The apples in the interior of the crown appear more susceptible than those on the periphery. (Uncoloured fruit, see under Maturity at harvest, Tiller, 1933.)

Wickens and Carne (1927[1]) consider that in Cleopatra terminal fruits are more liable to tree-pit than lateral fruits.

Pruning

McAlpine (1915, 4th Rept., p. 66). Severely pruned trees had invariably the most pit, and at the other extreme of no pruning there was comparatively little pit.

Kaiser (1923). Drastic pruning especially in summer favours the disease.

Smith (1926) points out that McAlpine refers only to pit developing on the trees.

Carne, Pittman and Elliot (1929) agree that McAlpine's finding is generally recognized by growers.

Thinning fruit and blossom

McLarty (1928) reports that drought spot in British Columbia is found on trees thinned heavily, lightly or not at all, and on trees bearing heavy, medium or light crops.

Wallace (1934). With Early Victoria at Long Ashton removal of 50% of the blossom trusses has been associated with a high percentage of bitter-pit in low temperature store. Fruit thinning to one fruit per truss has not affected bitter-pit.

Ringing

McAlpine (1915, 4th Rept.) carried out ringing experiments with inconclusive results.

Mix (1916) failed to produce bitter-pit or any corky disease by girdling branches, though he noticed that a branch partly girdled by canker produced the true fruit-pit or stippen while the fruit on other branches was clean.

Heinicke (1921). Fruit on wood weakened by ringing early in the season is more prone to develop bitter-pit in U.S.A.

Wallace (1934). At Long Ashton ringing has sometimes produced cork in hot dry years. On bitter-pit the effect has been insignificant even when yielding consistent effects on other troubles.

Size of crop

See Seasonal pitting.

Maturity at harvest

Jaeger (1869), who, according to McAlpine (1912, 1st Rept.) provides one of the first recognizable allusions to the disease, considered the cases under his observation to have been caused by placing early maturing fruit in a damp cellar without first keeping it for some time in a dry atmosphere.

The following recent workers find that bitter-pit (storage-pit) is definitely associated with immaturity at picking :—

Brooks and Fisher (1918).

Adam (1923, 1924).

Overholser and Fidler (1922-3).

Overholser (1927), Carne and co-workers (1927, 1928, 1929, 1931).

Wickens and Carne (1927[2]).

Barker (1930[1]).

Tiller (1930).

Allen (1931).

Empire Marketing Board 46 (1931) assembles more evidence and the conclusion is reached that " it appears to be definitely established that later picking reduces the development of bitter-pit in some instances to negligible proportions". No relationship has been established between maturity of fruit on arrival in country of import and degree of pitting.

Tiller and Chittenden (1933). Cox's Orange Pippin. " Where significant differences were obtained there was more bitter-pit in the earlier pickings than in the later." However, Tiller is not able to draw reliable conclusions on this occasion owing to the uniform maturity of the different pickings. With Cleopatras the fruit of later pickings showed more pit. To account for this reversal of the results with all other varieties Tiller suggests that " pronounced susceptibility to bitter-pit may be a characteristic of the uncoloured type of fruit which is to be found on the inner and lower limbs of the tree even late in the season. It seems more likely that some such phenomenon is responsible rather than that the green coloured fruit is actually immature, for, if the later picking were really the less mature of the two, one would expect it to be relatively more free from internal breakdown, whereas the reverse is actually the case."

The following cannot consider as proved that bitter-pit is produced in apples by picking them before they are sufficiently mature :—

KAISER (1923). Late harvesting favours the disease.

TINDALE (1932) considers his results show rather that susceptible fruit was borne on particular trees rather than that it had attained a certain maturity.

WALLACE (1934). At Long Ashton the effect of time on picking has been inconsistent.

[The importance of full data as to the state of maturity at picking for the correct evaluation of results of experiments is clearly shown.—ED.]

Size of fruit

CRAWFORD (1886), who first described the disease in Australia, was informed by a local grower that certain varieties are liable to these spots and that they are most in evidence (in storage) after a short crop, when presumably the apples are large. With normal crops the larger apples are spotted but not the smaller.

SEUFFERHELD (1900) considers that large smooth skinned apples are liable, but not large rough skinned sorts. (For his reasons see Physiological origins.)

STEWART (1900) expressed the opinion that large fruits are more affected than small ones of the same variety.

MCALPINE (1916, 5th Rept., p. 31). " . . . showing conclusively that pit is developed in a regular and progressive manner according to the size of the apples on the trees."

The following are more recent authorities :

SMITH (1926). " It is clear . . . from experiment as well as experience that the larger apples are more susceptible to bitter-pit than smaller ones from the same tree." This remark is in connection with a statement that young trees, light crops, and large apples are circumstances accompanying each other.

OVERHOLSER (1928) found that most pitting occurred on the largest apples.

EMPIRE MARKETING BOARD No. 46 (1931) shows and illustrates by graphs that a comparatively small increase in size is accompanied by a marked increase in susceptibility to pitting. Referring to Smith (above) it produces data to show that differences in the average size of apples were not responsible for the greater extent of pitting in light crop years.

TINDALE (1932). " Percentage of tree-pitting was abnormally high. . . ." This may be accounted for by the fact that " . . . the trees were bearing very light crops, consequently the few apples were very large."

CARNE (1932) gives $2\frac{1}{2}$ inches in diameter as the maximum size at which Cox's and other susceptible fruit can be safely exported in half-crop years.

Iodine maturity test

BIGELOW, GORE AND HOWARD (1905), first used.

CARNE (1928) describes.

CARNE (1929) describes and discusses value as test of maturity.

ANON (1929[1]) gives proof of the current indications achieved by the iodine test, but points out a weakness.

CARNE, PITTMAN AND ELLIOT (1929) discuss rapid chemical changes in picked apples ; the iodine test can only safely be applied to fruit at time of picking.

BARKER (1934) suggests a thorough trial in conjunction with observations of ground colour.

TILLER (1934) describes recent experiments with the iodine test on Cox's, Jonathan, Delicious, Sturmer and Statesman. He considers it on the whole to be of doubtful value for these varieties.

Mechanical pressure maturity test

CARNE, PITTMAN AND ELLIOT (1929) found the mechanical pressure tester less reliable and less foolproof than the iodine test.

Seasonal pitting

McAlpine (1912, 1st Rept.). "There was general agreement that a light crop was most affected by the disease."

Palmer (1925, 1931) states that in Canada Jonathan breakdown occurs far more freely in fruit from lightly bearing trees than from those with a heavy crop.

Smith (1926). ". . . bitter-pit is especially prone to occur in fruit from young trees or from trees with light crops and therefore with large apples." In this connection E.M.B. 46, 1931, shows that the size of the apple has no influence on the greater degree of pitting in light crop years.

Butler, O. (1928). ". . . more serious pitting in Baldwin apples during years of light bearing. . . ."

New Hampshire Agr. Exp. Sta. (1928) reports correlation between low productivity and incidence of bitter-pit.

Carne (1929) ". . . generally accepted the idea that small crops and consequent large fruits are very liable to bitter-pit". E.M.B. 46 (1931) notes that Carne considers this idea has reference to cork rather than bitter-pit (see Differentiation between bitter-pit and other corky diseases, under Carne, 1929).

Empire Marketing Board 46 calls attention to the striking difference in the incidence of bitter-pit during the 3 seasons of the Empire Marketing Board's dock survey, particularly in Tasmanian apples, notably Cleopatra and Sturmer Pippin, but also in less susceptible varieties. It is suggested that the seasonal variation may be related to the size of the crop, 1927 and 1929, years of light crop, showing the heaviest pitting. In 1928 a bumper crop had comparatively little pitting. Bitter-pit here means the storage pit of Carne (1929), see Differentiation between bitter-pit and other corky diseases. E.M.B. 46 does not postulate the size of the crop as being the only possible explanation of seasonal variation in pitting. Climatic or other conditions may be predisposing causes. It is considered that useful results might follow an enquiry into the influence of yield on pit susceptibility.

Carne (1932). Fruit from light crops of Cox's and others cannot be exported without developing bitter-pit or breakdown or both. Apples of these varieties of over $2\frac{1}{2}$ inches in diameter are dangerous for half crops and apples from smaller crops should never be exported.

Overholser and others (1933). A light crop is associated with the development of cork and drought spot owing to withdrawal of water from the fruits by the luxuriant foliage during periods of excessive transpiration. Instance cited of portion of an orchard severely defoliated by insect attack producing much lower percentage of cork spot than the less defoliated section.

Seed content

Heinicke (1921). Tree-pit. The distribution of the seed within the fruit seems to determine the position of the spots on the surface, especially in shaded fruit. (Spotted side—poor seed or empty seed cavities.) Affected fruits average lower seed content and more poor seeds.

Storage-pit. New pits appear in storage more abundantly on the large many-seeded sides of unsymmetrical fruits. (For good summary of Heinicke's paper see Heald, (1926).)

Soft v. hard fleshed varieties

Sorauer (1909). The disease affects mostly soft fleshed early varieties.

Scientist (1911). Prevalent in both, but to a less extent in hard fleshed varieties.

Uncoloured fruit

See Maturity at harvest, under Tiller (1933).

Varietal susceptibility

Crawford (1886) received a short list of susceptible varieties from a local grower : i.e. Downton Nonpareil, Old Nonpareil, Pennington Seedling, Dutch Mignonne, Lord Nelson.

Jones (1891). Baldwin in U.S.A.

Stewart (1900). Baldwin, Northern Spy, Rhode Island Greening.

Güssow (1906). Warner's King, New Hawthornden, Lord Grosvenor, Allington Pippin—all are soft fleshy fruits.

Lounsbury (1910) gives a list of susceptible varieties in various parts of the world.

Kirk (1911) gives a list of affected varieties in New Zealand.

Kaiser (1923) gives a list of (1) highly susceptible, (2) susceptible, (3) resistant, and (4) immune varieties in Germany. Cox's Orange is in class (2), and Gravenstein in class (4). The first fruits of normally resistant varieties are liable to be attacked.

Gardner (1928). King David apples in Indiana.

Carne (1928) gives list of varieties most affected by storage pit, and a list of those most affected by blotchy cork. (See Differentiation of bitter-pit, Carne, 1929.)

Barker (1928[2]) gives the following wastage from bitter-pit in Australian fruit on arrival in England : Tasmanian Cox's 21%, Cleopatra 10%, Ribston 9%, Sturmer 9%, Western Australian Cleopatra 18%.

Empire Marketing Board 46 (1931) gives a list of percentages of bitter-pit observed on arrival in England of twenty-two Australian and New Zealand varieties during 1927-29. The state or country of origin is indicated. It considers New Zealand apples to be definitely less subject to pitting than Australian apples. Seasonal pitting is also more marked in certain varieties.

Sherbakoff (1932) gives some observations on varietal reaction to bitter-pit in Tennessee.

Wallace (1934). Low temperature (1° C., humidity 95%) failed to control bitter-pit at Long Ashton with Early Victoria. With other varieties low temperature has usually effected substantial control. Exceptions occurred in 1933, an abnormally hot dry season.

Predisposition

See Barker (1934), under Physiological causes.

STORAGE

Kidd (1934) supplies a guide for future experiments in storage. No consistent evidence is available, he says, regarding the effects of storage conditions on the recovery or otherwise of apples which though diseased have not yet developed necroses. The experience gained in the study of low temperature breakdown, Jonathan breakdown and gas injury should be a useful guide in future experiments. Temperatures below tolerance limits may delay the appearance of necroses but be also adverse to recovery. It is possible that mean temperatures may prove optimal for recovery. The effect of cooling before, during and after the climacteric rise in respiratory activity should be studied in connection with recovery from predisposition to bitter-pit as has been done in regard to breakdown in cold store. Ethylene stimulates the immediate onset of the climacteric rise in gathered fruit. Carbon dioxide markedly retards it. By experimenting with these two agencies definite results might be obtained as to whether recovery depends upon fruit being in its pre-climacteric state. It would be interesting to discover whether damaging carbon dioxide concentration can ever be reached in fruits on the tree as a result of (1) high temperature (external factor), (2) high specific respiratory activity (internal factor), (3) insufficient internal ventilation arising from closure of intercellular air spaces and surface apertures as a result of injection and surface wilting.

Barker (1934), Wallace (1934) suggest points on which investigations could usefully be made.

Storage temperature

Diakonoff (1910). Due to hastened ripening on tree or in storage.

McAlpine (1911-16, 1st-5th Repts.) found that 31° F.-32° F. was the most suitable storage temperature for the prevention or retarding of bitter-pit. Higher, or, in particular fluctuating temperatures (See Fluctuations in temperature in store) failed to restrain it. Smith (1926) considers McAlpine's experiments are open to criticism, as the alleged temperature of the ships' holds is quite unreliable.

Adam (1923). Dunn's Seedling stored for 8 months showed 26% bitter-pit at 34° F., against 16% at 32° F. (Australia.)

Adam (1924). An opposite result was obtained next year with Annie Elisabeth, which in 5 months storage showed more bitter-pit at 32° F. than at 35°-37° F.

Smith (1926) in Australia confirms the retarding effect of temperatures of 33°-34° F. on Tasmania, Ribstons and Cox's Orange Pippins. He notes the opposite result obtained by Carne when badly pitted Western Australian Cleopatras developed bitter-pit rapidly at 33°-35° F. but practically none at 60°-80° F., and shows how these two apparently contradictory results can be reconciled.

Wickens and Carne (1927[2]) conclude that bitter-pit can originate in apples after picking and that with very susceptible varieties cold storage may increase the final amount of pit by prolonging the period of susceptibility.

Overholser (1928) at Berkeley, U.S.A., found in 1922 with Gravensteins little difference in percentage affected at 32°, 36° and 45° F., but the attack was appreciably delayed and much less severe at the lowest temperature. In 1924 with Gravenstein held at similar temperatures the percentage affected was greatly increased with the higher temperatures as was the degree of severity.
Further evidence in support of the retarding influence of a lower temperature on bitter-pit development in shipments will be found in Anon (1929[1]), Tiller (1930), Barker (1930[2]).

Tiller (1930 and 1933) questions the economic value of the lower temperatures especially for Cox's. The incidence of breakdown is increased and the retarding effect vanishes on removal from store. Storage temperature has less effect on a strain of good keeping quality than on a strain liable to pit.

Evans (1932). Bitter-pit a cause of heavy loss in South Africa. In experimental consignments deck consignments arrived in England practically free from bitter-pit, whereas in those stored bitter-pit increased in severity as temperatures were raised from 32°-40° F. A minimum of this trouble occurs around 70° F.

Allen (1932), taking as his text Carne's (1927[2]) theory that bitter-pit was a "necrosis of immature starch filled tissues of rapidly growing apples resulting from excessive transpiration, followed by osmotic action between the starch filled cells and those in which the starch has been largely or completely changed to sugar", and having other data of his own (Allen, 1931) (See Storage, Ethylene Gas) made further experiments over two years. From these he concludes that (*a*) "while a low temperature of 32° F. will retard bitter-pit, its development on immature fruit after removal from storage will be rapid," and (*b*) "fruit harvested and held continuously at a temperature of 70° F. or higher will develop the minimum amount of bitter-pit at and during the time it is in the best condition for eating". He admits that more extensive tests are necessary to find whether the results can be wholly explained by Carne's theory. It may be mentioned that the starch content of Allen's apples held for 10 days at 70° F. was only half that of comparable lots at 50° F., at which temperature the fruit became most severely disorganized.

Wallace (1934). Low temperature storage (−1° C., 95% humidity) has usually given control over bitter-pit at Long Ashton. Certain exceptions are mentioned, notably Early Victoria, and in 1933, an abnormally hot dry year, certain other varieties.

Fluctuations of temperature in store

McAlpine (1913, 2nd Rept.) relates experiments to show that the development of bitter-pit can be quickly produced by fluctuations of temperature and humidity (in combination) in cool storage. His temperatures varied from 34°-60° F. Smith (1926) considers these experiments uncritical.

Delayed cold storage

Smith (1926). Delayed storage results in considerable development of bitter-pit in the interval and renders less effective the retarding influence of subsequent cold storage. The loss of retarding effect may be apparent only in that owing to the delay a number of apples may have been on the point of developing bitter-pit when placed in the store. (See Precooling.)

Precooling

Barker (1934) alludes to an experiment in 1932 which showed that precooling resulted in considerably more bitter-pit than delayed cold storage (q.v.). He considers further work on immediate and delayed cold storage desirable.

Humidity in storage

Kaiser (1923). Apples stored in dark, well ventilated, not too dry cellars showed less bitter-pit than those kept in dry rooms.

Barker (1934) makes suggestions for experiments on the effect of humidity in storage. So far, he says, no experimental work on this aspect appears to have been done.

(See also Fluctuations of temperature in store under McAlpine (1913.))

Ethylene gas treatment

Allen (1931). Bitter-pit cannot be prevented by this treatment, but its severity may be reduced. Hastening of ripening by ethylene results in a smaller amount of pit. Fruit held for immediate ripening developed less bitter-pit at 70° F. than at 50° F., hence more rapid ripening by higher temperatures may accomplish the same results as ripening by the use of ethylene. (See Storage temperature.) Quotes Carne (1927) to show that bitter-pit develops primarily on immature fruit, and that cells adjacent to infected areas contain higher percentage of starch. Quotes Harvey, R. B. (Artificial ripening of fruits and vegetables. *Minnesota Agr. Exp. Sta. bull.* **247**, 1928) to show that starches are quickly digested under ethylene treatment.

Allen (1932). Three treatments of ethylene gas at 1 in 1,000 at a temperature of 70° F. gave some indication that the gas decreased the incidence of bitter-pit by accelerating starch dispersion. No effect was produced by the gas at 50° F. The variety was Gravenstein.

Kidd (1934) and Barker (1934) refer to the need for further experimentation with ethylene treatment.

Gas storage

Kidd, West and Kidd (1927). Apples affected with bitter-pit before or after harvest are particularly liable to internal breakdown later in storage life.

Kidd (1934) supplies a guide for future experiments. (See under Storage.)

Barker (1934) says that, even if gas storage has no effect on the development of bitter-pit, its retarding effect on breakdown might allow of a later maturity at picking with a consequent diminution of bitter-pit. He gives the gas storage conditions most suitable for English Cox's, i.e. oxygen 2·5%, carbon dioxide 5% at 40° F.

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